MEMORANDUM REPORT ARBRL-MR-03134

# DETAILED THERMAL RESPONSE OF A 155-mm, M203 PROPELLING CHARGE DURING TEMPERATURE CONDITIONING, HANDLING, AND LOADING

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Extreme temperature conditioning of large-caliber propelling charges for a determination of temperature coefficients is a very important phase of charge design evaluation. Ambient conditions encountered during transit from conditioning chambers to gun sites have a profound effect on temperatures of conditioned charges. The M203, Zone 8 Propelling Charge for the Army 155-mm Howitzer contains a complex ignition train whose vulnerability to those ambient conditions must also be considered. Two M203 charges were instrumented with thermocouples

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) located at ten positions and subjected to extreme temperature conditioning. Temperatures at these positions were monitored during conditioning and exposure to new environments. A 24-hour period for conditioning to extreme temperatures was shown to be sufficient, in agreement with past results as well as with current testing procedures. However, exposure to a new environment (e.g., removal from the conditioning box) leads to rapid changes in charge temperatures, particularly at the surface of the charge. The influence of this response on performance is unknown but potentially important.

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# I. INTRODUCTION

Standardized ammunition safety performance test procedures require a determination of temperature coefficients to establish upper safe pressure levels for various weapons. For this phase of testing, ammunition is conditioned at temperatures ranging from -54°C (-65°F) to +68°C (+155°F).

The US Army Test and Evaluation Command outline for limits of operation requires that for testing ammunition at 21°C (70°F) propellant temperature will not vary more than ±0.5°C at time of firing. Further, for extreme temperature testing (-54°C to +68°C) propellant temperature must not vary by more than ±2.5°C at time of firing[1].

Times have been fairly well established for complete temperature conditioning of ammunition;[2] however, the environmental conditions this ammunition will encounter before being fired may have an enormous effect on the temperature at time of firing. Time of exposure to ambient air and wind conditions, direct rays of the sun and weapon temperature are but a few of the environmental conditions which can exert a strong effect on a conditioned charge. Anderson and Heppner[3] did an extensive study on temperature change versus exposure time by imbedding thermocouples in a variety of charges and projectiles, and monitoring the temperatures during the initial conditioning process and after removal to a different atmosphere as might be encountered while moving those ammunition items to a gun site.

Seemingly, previous studies were devoted to ascertaining propellant temperatures under a variety of conditions, but we feel consideration should also be given to the individual components of the ignition system, in particular, of a large-caliber propelling charge. Therefore, the present study was undertaken to determine extreme conditioning times and the effect of a new temperature environment on the ignition system as well as the propellant by inserting thermocouples at selected locations in a typical high-performance artillery charge, the 155-mm, M203 Propelling Charge.

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[1] *"Abnormal Temperature Testing of Artillery, Mortar and Recoilless Rifle Propellants," USATECOM Material Test Procedure No. 4-2-608, Aberdeen Proving Ground, MD, 20 February 1971.*

[2] *D.J. Francis, "Final Report of Research Study of Ammunition Temperature Conditioning Time Requirements," Report DPS-1665, Aberdeen Proving Ground, MD, May 1965.*

[3] *H.B. Anderson and L. Heppner, "Special Research Study on Temperature Change Versus Exposure Time for Extreme Temperature Conditioning of Artillery Ammunition," Report No. APG-MT-3571, Aberdeen Proving Ground, MD, July 1970.*

## II. EXPERIMENTAL

### A. Thermocouples

The thermocouples were made by forming a junction between 24-gage enameled copper wire and 27-gage constantan wire, the resulting junctions having a diameter of approximately 1.2 mm. Of the 27 prepared, 23 were selected based on their uniformity of response during immersion in water at 25°C, water at 100°C, and a dry ice-acetone mixture at -78.5°C.

Temperatures were read directly from a Multipoint Digital Thermometer which is portable, battery operated, and reference-junction compensated. The unit is capable of indicating the output of any 1 of 10 thermocouples with like inputs to ±0.1°C. A switching device was inserted between the thermocouple leads from the charges and the digital readout unit, which expanded its capability of indicating the output from any 1 of 23 like thermocouples.

### B. Preparation of Charges

Two standard M203 charges were dismantled so that thermocouples could be inserted at selected points. Figure 1 shows the locations selected for the insertion of the thermocouples. The two charges were rebuilt simultaneously so that the least variation in thermocouple placement would result.

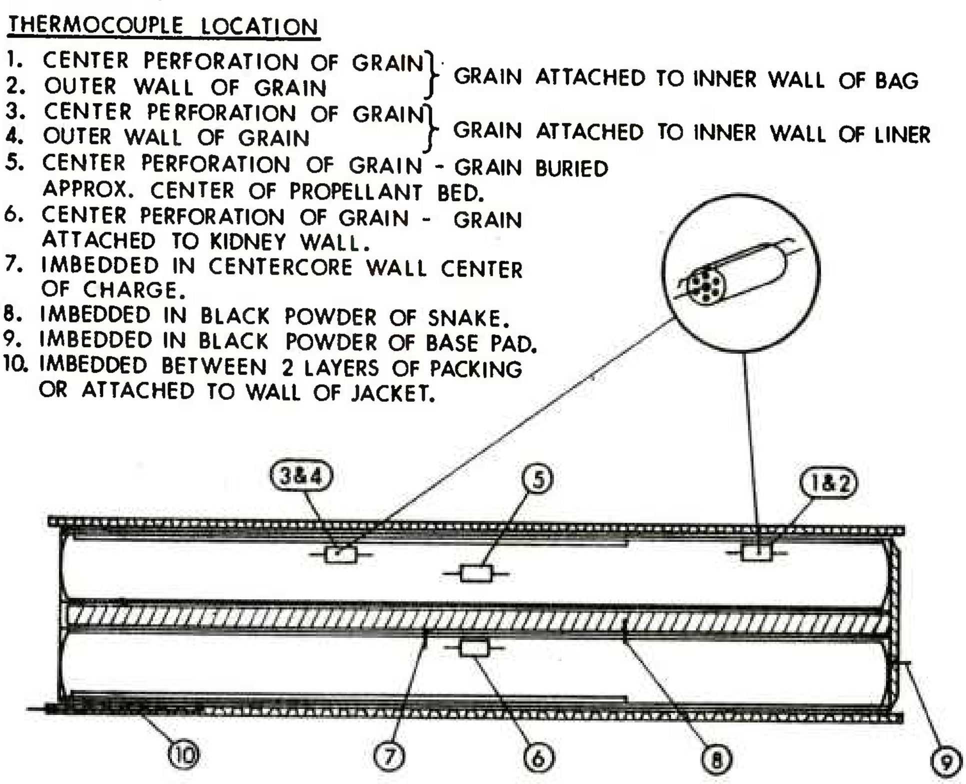


Figure 1. Location of Thermocouples Within the M203 Propelling Charge

Thermocouple No. 8 (TC-8) was inserted through the cloth wall of the snake and imbedded in the black powder at the midpoint of the snake. The lead wires were strapped to the outer walls of the snake, extending several inches beyond the forward end.

The snake was repositioned within the centercore tube, and TC-7 was inserted in a small hole drilled into the 3.5-mm thick sidewall of the centercore at its midpoint, longitudinally. Care was taken that this junction was truly imbedded in the wall and did not penetrate through the wall. TC-7 leads were strapped to the centercore walls so that they too extended beyond the forward end of the tube.

Several of the 7-perforation propellant grains were instrumented with thermocouples. TC-2 was cemented into a shallow groove cut into the side of a grain, and TC-1 was inserted into the center perforation of the same grain, this perforation having been enlarged to accomodate the 1.2-mm diameter of the junction. The same procedure was followed with TC-3 and TC-4, TC-3 inserted into the enlarged center perforation and TC-4 cemented in a shallow groove cut into the wall of the grain.

The propellant grain bearing TC-1 and 2 was attached to the inner wall of the bag, 15 cm from the base end of the charge, and the grain bearing TC-3 and 4 was attached to the wall of the $TiO_2$ liner, inside the charge, at a point 15 cm from the forward end of the charge. The grains were attached to these surfaces so that TC-2 and 4 were at the interface formed between the grain and the surface to which it was attached. The leads from these four thermocouples were brought out the forward end of the bag.

Another grain, instrumented with TC-6 through its center perforation was attached to the kidney wall at the midpoint of the charge, and its leads also brought out of the forward end of the bag.

With the grains bearing TC-1, 2, 3, 4, and 6 attached firmly inside the bag, one-half the propellant load was replaced, and another grain with TC-5 through the center perforation was placed on the surface of the propellant bed and its leads forced through the bag wall at that point. Care was taken so that this grain was centered within the space defined by the centercore wall and the outer wall of the bag. With this grain in place, the balance of the propellant load was added and the seam sewn shut.

With the instrumented centercore and snake in place within the charge and tie straps secured, TC-9 was imbedded in the black powder of the basepad and the leads brought up along opposing sides of the charge, and strapped lightly in place. The assembly of the charge was completed by the replacement of the lacing jacket. TC-10 was alternately taped to the outer surface of the lacing jacket or inserted between layers of the corrugated packing material surrounding the charge.

One charge was placed in the standard M203 metal shipping container lined with corrugated cardboard, and all TC leads brought through a small hole previously drilled in the lid. The second prepared charge was placed in a sealed plastic bag - a procedure often used to prepare experimental charges for conditioning.

C. Test Procedure

The two charges were extreme temperature conditioned in a chamber located at the Ballistic Research Laboratory Sandy Point Firing Facility. The chamber was designed for testing various ordnance items over a temperature range -73°C to +93°C. The chamber was allowed to operate for a period of 24 hours to stabilize at the desired temperature before the charges were placed inside.

After temperature stabilization of the chamber, both charges were laid horizontally upon a lattice shelf located an equal distance (45 cm) from the top and bottom of the conditioning chamber. Thermocouple leads extended outside the box and had previously been attached to the readout unit. The charges were placed inside the box in a minimum of time ($\sim$ 1 minute) so that recovery time to initial conditioning temperature would be as short as possible. For purposes of timing, time-zero was defined by the closing of the chamber door.

Although the conditioning chamber was equipped with a temperature recording device, a thermocouple (for reference labeled TC-amb) was inserted into the top of the chamber, extending inward by 15 cm. Excellent agreement was obtained between the two temperature indicating devices during the heating cycles of this study, but not during the cooling cycle. TC-amb was also used to measure ambient air temperatures, and to measure gun chamber temperature when the conditioned charges were moved to a new environment.

During conditioning, temperature readings at all locations were taken every 2 minutes for the first 30 minutes, every 5 minutes for the next 30 minutes, and every hour for the following 6 hours. No readings were then taken for 16 hours. Finally, the readings were conducted at half-hour intervals for 2 hours prior to removal of charges from the conditioning chamber.

## III. RESULTS

Figure 2 is a plot of the data, temperature vs time, obtained at five positions for a charge which had been placed in a chamber heated to +62°C. Temperature histories for positions not shown were in substantial agreement with those of corresponding positions plotted (i.e., positions 1, 2 and 4 similar to 3; positions 6 and 7 similar to 8). The charge was in the standard metal shipping container, and TC-10 imbedded between two layers of corrugated packing material wrapped around the charge. Figure 3 is a plot of the data obtained at the same four positions within a charge wrapped in plastic, also surrounded by the same corrugated packing material with TC-10 imbedded in that material. Although both charges were conditioned at the same time, the charge in the metal container appears to approach the chamber temperature somewhat faster than the charge in the plastic material. This observation can perhaps be ascribed to the faster heat conduction properties of the metal container over the plastic material.

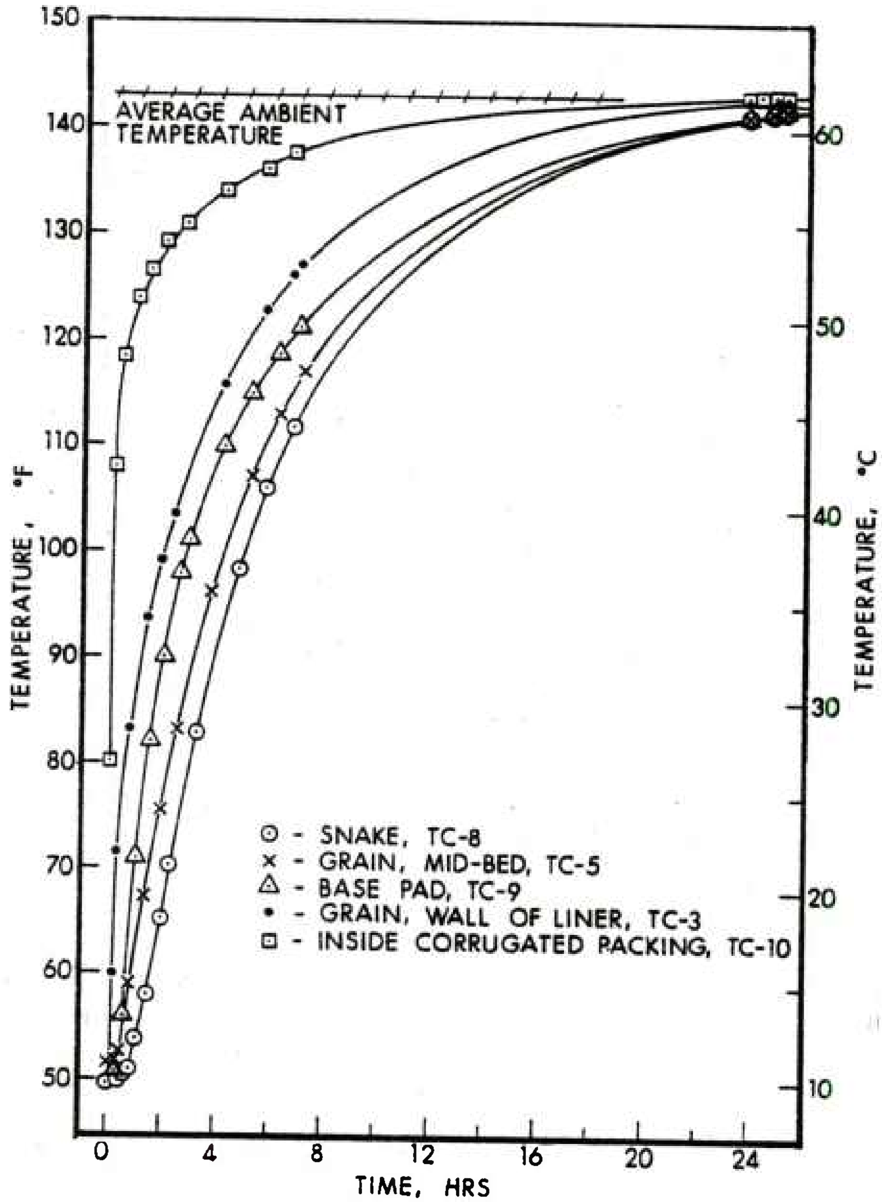


Figure 2. Time Required to Extreme Condition an M203 Propelling Charge in Metal Container

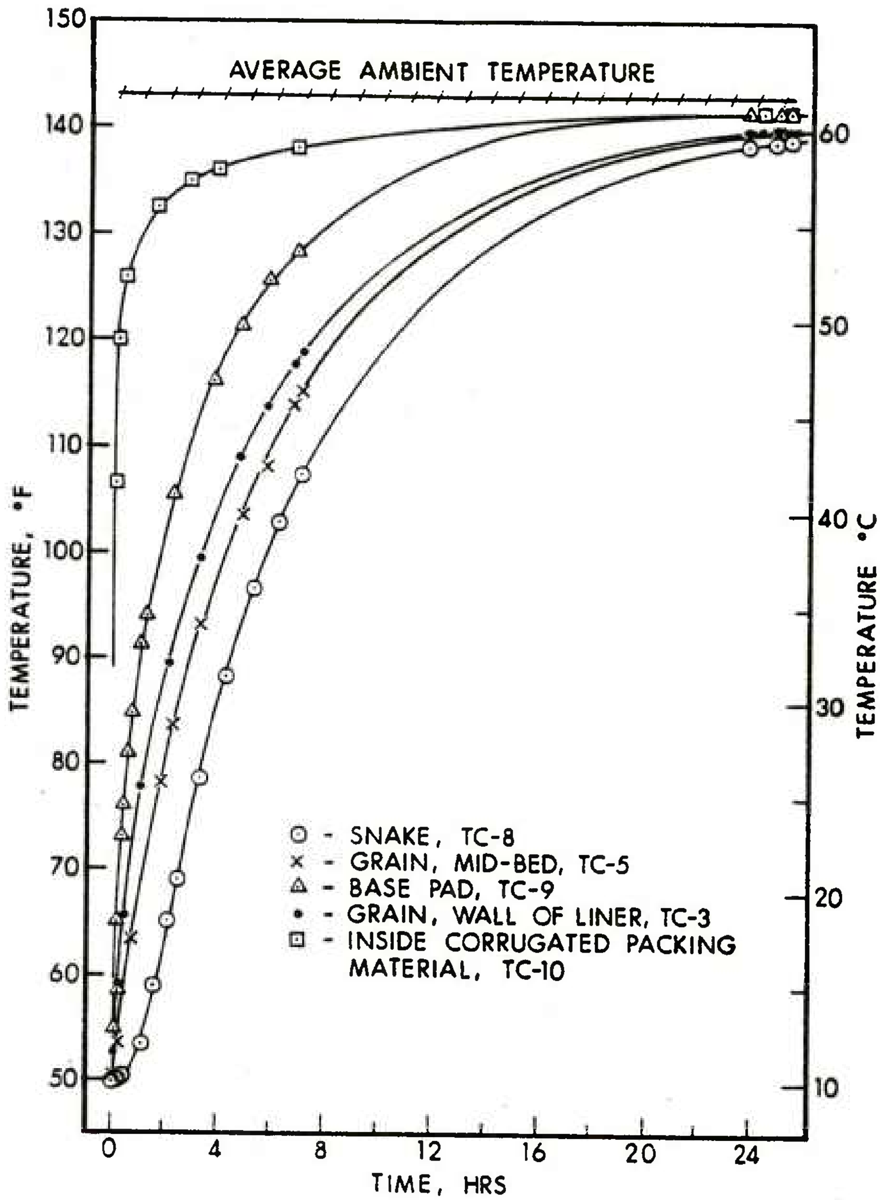


Figure 3. Time Required to Extreme Condition a M203 Propelling Charge in Plastic Wrap

Figures 4 and 5 show the temperature vs time plots of the data obtained when these two charges, in their containers, were removed from the conditioning chamber and laid on a wooden surface in a draft-free room, in which the ambient temperature was 15.6°C. The time of transition from conditioning chamber to the new environment was less than 2 minutes, and monitoring of the thermocouples began at 2 minutes and continued for 1 hour. Note the accelerated cooling of exterior components (corrugated packing and basepad) in the plastic wrapped charge versus the containerized charge.

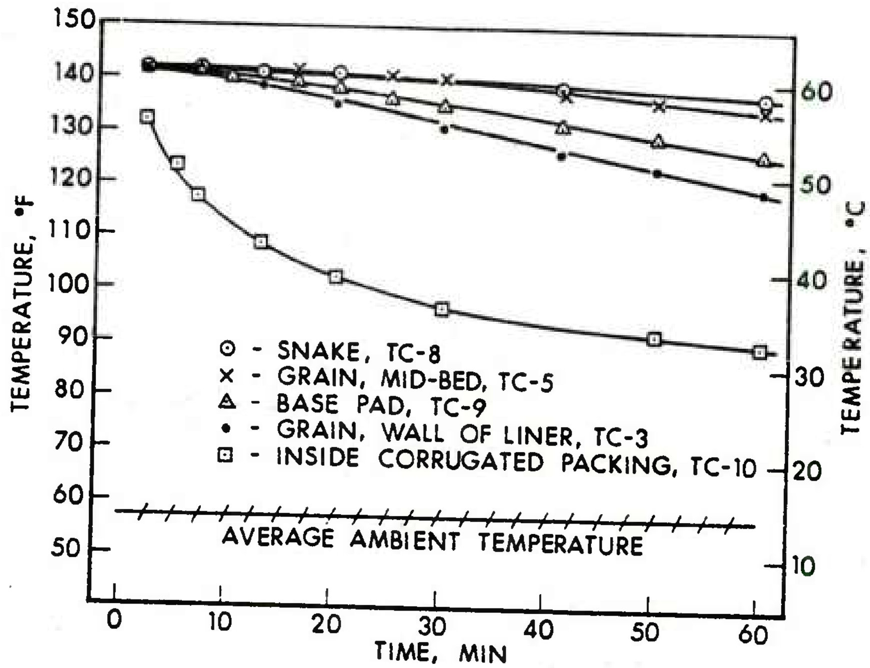


Figure 4. Effect of 15°C Environment on Containerized Charge Conditioned at 62°C

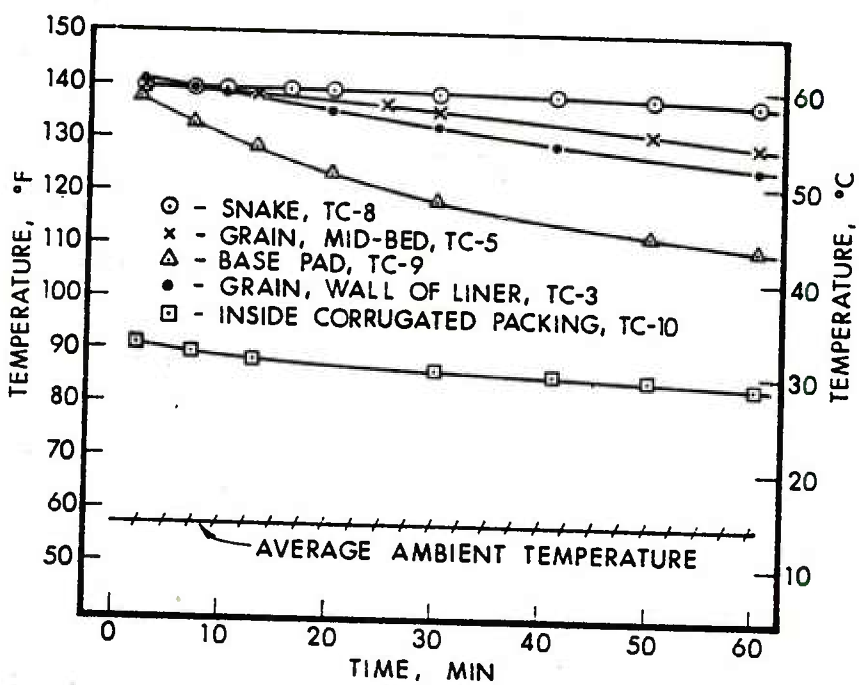


Figure 5. Effect of 15°C Environment on Plastic Wrapped Charge Conditioned at 62°C

Figure 6 is a plot of temperatures recorded at various points within the containerized charge during reconditioning to approximately 62°C. After 24 hours, the container and charge were removed from the conditioning chamber and transported to a gun site where the charge was removed from the container and placed inside the gun chamber at 16°C. The total transition time to the new environment was 2 minutes. Before temperature reconditioning, TC-10 had been removed from the corrugated wrapping, and secured to the jacket surface. Figure 7 shows the rate of cooling upon transition to the gun site and insertion within the gun chamber.

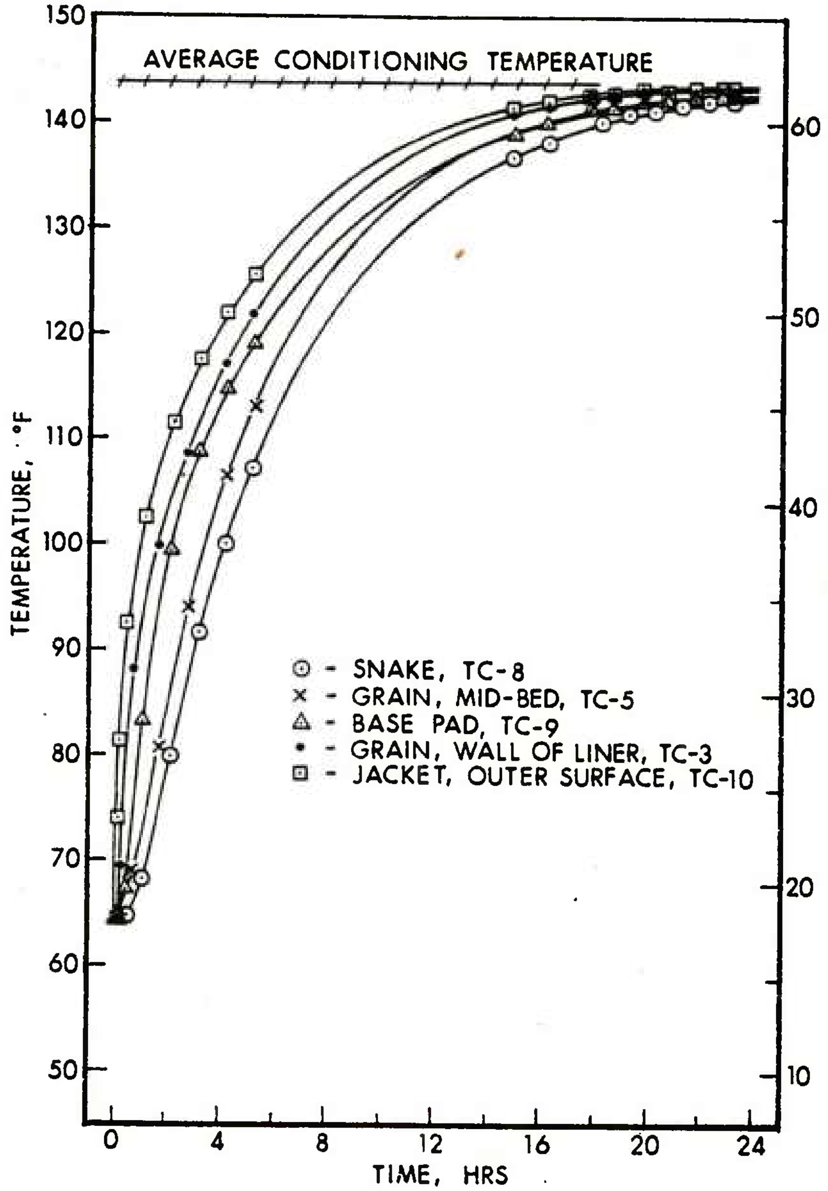


Figure 6. Time Required to Recondition an M203 Propelling Charge in Metal Container

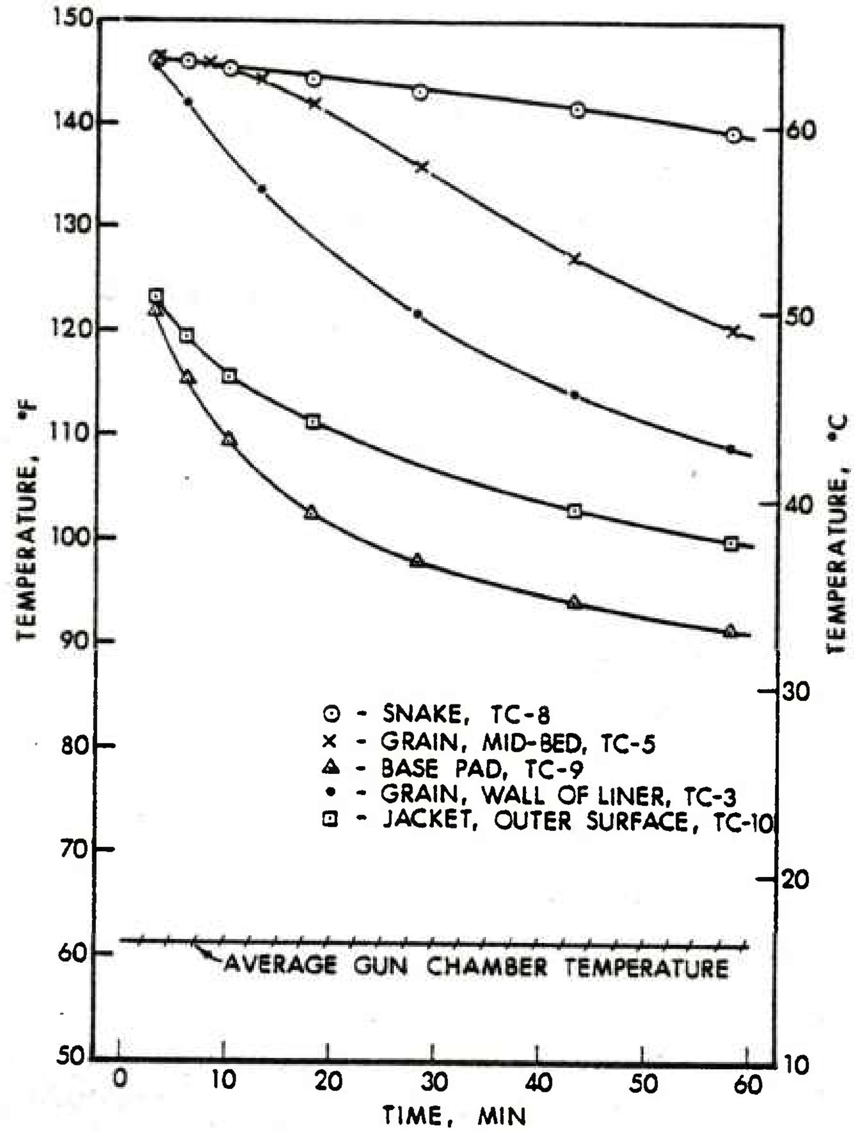


Figure 7. Cooling Effect of Gun Chamber at 16°C on Charge Conditioned at 62°C

To determine the time required for all components of a containerized (metal) M203 Propelling Charge to become cold conditioned, the conditioning chamber was first allowed to come to equilibrium, as indicated by the recording device of the chamber, and the charge was then inserted. Figure 8 is a temperature vs time plot of thermocouples at four locations within the charge, and TC-10 on the jacket surface. After a 24-hour conditioning period, the containerized charge was removed from the conditioning chamber and from the container, (transition time of < 2 minutes) and laid on a metal surface in a draft-free room at +25°C. Figure 9 is a temperature vs time plot of temperatures recorded at four locations within the charge and at the jacket surface.

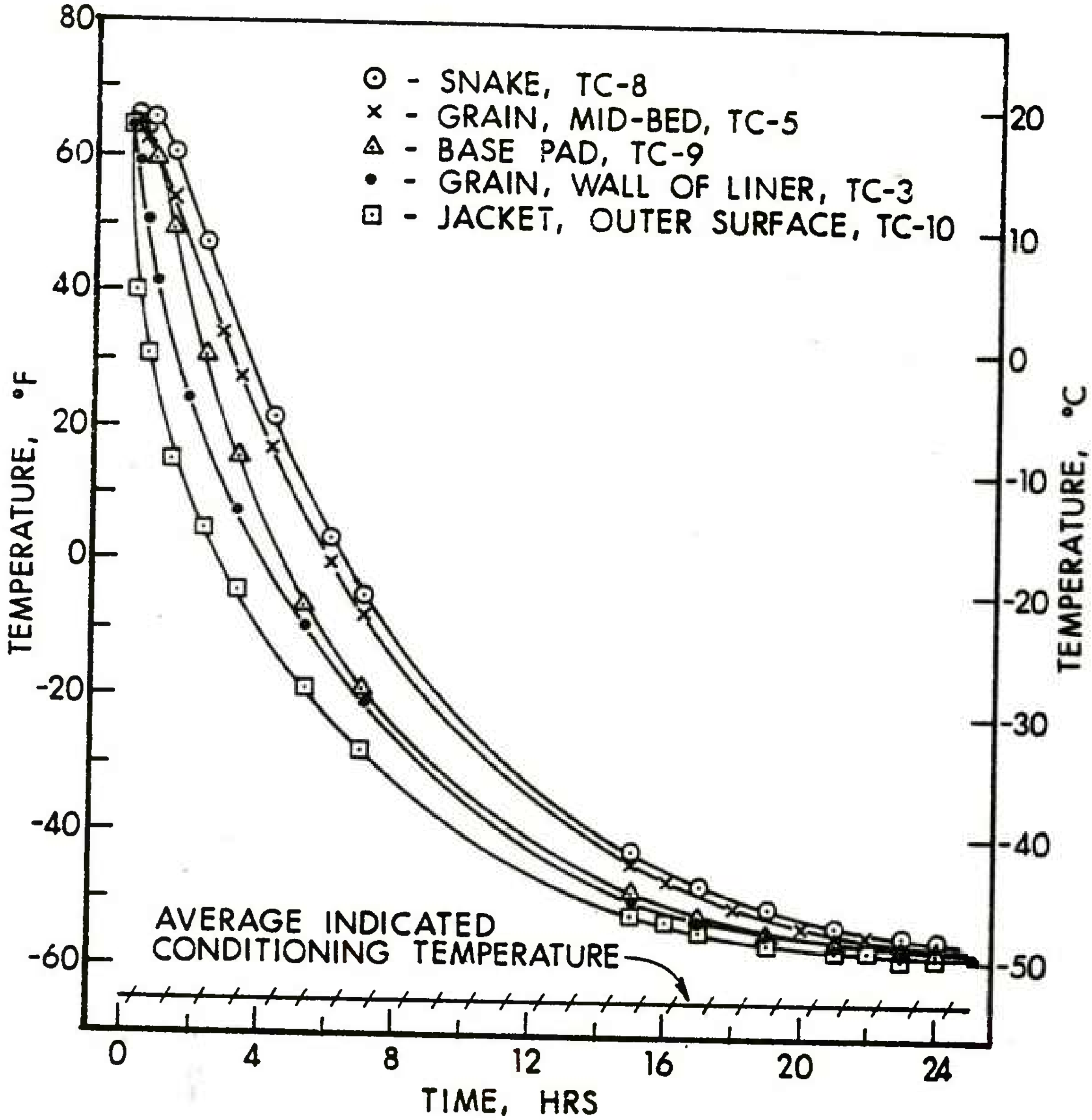


Figure 8. Time Required to Condition a Containerized M203 Charge at -49°C

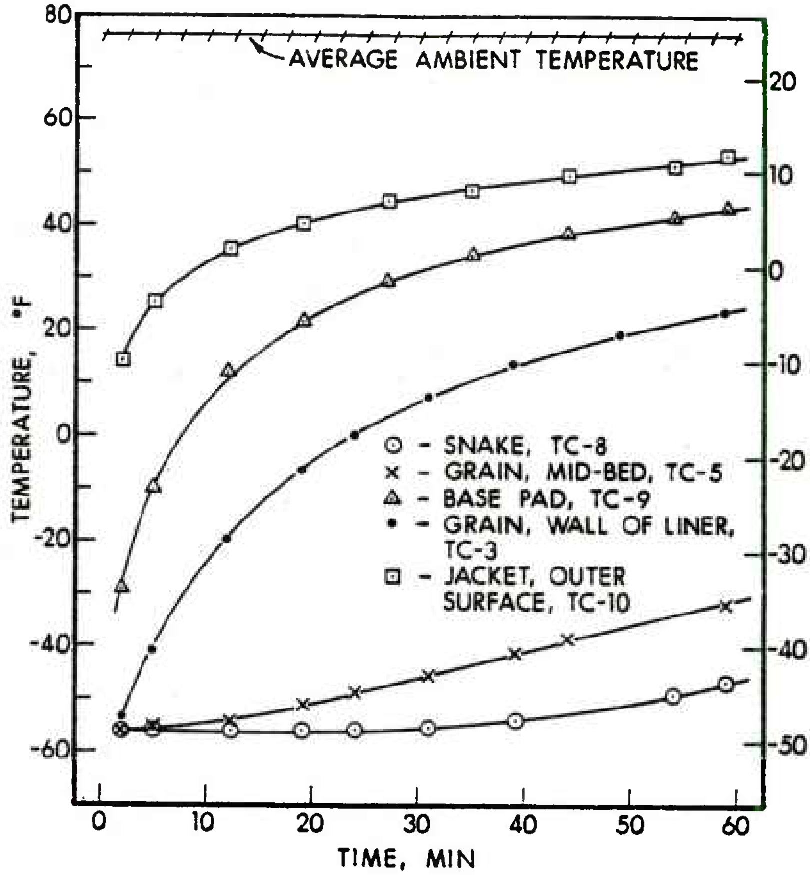


Figure 9. Effect of 25°C Environment on a M203 Charge Conditioned at -49°C

Near the end of the extreme-cooling cycle it became evident that strong thermal gradients apparently exist in the conditioning chamber used for this study. Anderson and Heppner suggest that conditioning boxes be checked for this problem by placing several thermocouples at various locations within the chamber and noting any variations in temperature. Although the temperature chart recorder for the chamber used in this study indicated a temperature of -54°C during the cold conditioning cycle (Figure 8), the temperatures within the charge had not reached that temperature after 24 hours of conditioning. An extrapolation of those curves indicates that the temperature of the charge would probably never reach -54°C. Perhaps this was to be expected, since the chart-recorder sensor was located near the bottom of the chamber and the charge was laying on a shelf located in the center, 45 cm above the bottom. A thermocouple (TC-amb) extended 25 cm into the upper section of the chamber indicated a temperature of -47°C while an immersion thermometer extending 7.60 cm into the upper section of the chamber indicated a temperature of -45°C.

## IV. CONCLUSIONS

Testing was performed to study the thermal response of various stations in a 155-mm bagged charge to extreme conditioning temperatures. The times required to condition such a charge to nearly uniform extreme temperatures throughout were measured and found to be in agreement with the earlier work reported by Francis[2]. A 24-hour period appears to be adequate for conditioning this charge to both hot and cold temperature extremes. Exposure time to a new environment, however, was shown to exert a strong influence on the established temperature profiles within the propelling charge and the basepad, and,to a lesser extent, other ignition system components. This behavior may in part be responsible for observed variations in ignition delays, as the burning rate for black powder is strongly affected by initial temperature[4]. Further, it may be concluded that without extreme care to provide adequate thermal protection and minimum exposure times between conditioning chamber and moment of firing, significant variations in propelling charge performance may be observed; test results may not be truly representative of those expected in the arctic and desert environments that such tests are intended to simulate. We note that the plastic wrapping employed in this test provided a thermal barrier that was far less effective in this respect than the standard metal shipping container supplied with the M203 Charge.

A final caution is made to ensure that strong thermal gradients are not present in the conditioning chamber, as they may further degrade validity of test results.

[4] *Private communication, K. J. White, Interior Ballistics Division, Ballistic Research Laboratory, Aberdeen Proving Ground, MD.*

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